AD-752 747

OPTIMUM SERVICE LIFE DETERMINATION TECHNIQUE

Logistics Management Institute

Prepared for:

Assistant Secretary of the Navy (Installations and Logistics)

November 1972

AD752747

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WASHINGTON, D.C. 20016

UNCLASSIFIED

Security Classification

UNCLASSIFIED DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Logistics Management Institute 4701 Sangamore Road Washington, D. C. 20016	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

Optimum Service Life Determination Technique

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 1972	67	31

8a. CONTRACT OR GRANT NO. SD-271 b. PROJECT NO. c. SD-271-168 d.	9a. ORIGINATOR'S REPORT NUMBER(S) LMI Task No. 72-12 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT "A" Approved for public release; distribution unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Assistant Secretary of the Navy (Installations & Logistics)

13. ABSTRACT

This report describes efforts by LMI to determine feasible methods of attaining the following dual interrelated objectives:

1) Improved long-range predictions of the safe remaining structural life of groups of Naval aircraft (e.g., all Navy F-4Bs) to be used statistically to facilitate and support decisions regarding major structural modification programs, programmed aircraft model service life and service life extensions, and planning of the future military role to be filled by given aircraft models.

2) Improved short-range predictions of the structural condition of individual Naval aircraft, which can be used to develop a maintenance strategy (e.g., inspection intervals) which would increase the probability of aircraft meeting operational commitments without major structural problems.

Actions to achieve these objectives are recommended and discussed.

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OPTIMUM SERVICE LIFE
DETERMINATION TECHNIQUE

LMI Task 72-12

November 1972

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FOREWORD

The original objective of efforts described in this report was to determine a meaningful way to predict the safe remaining structural life of airframes of individual Naval airplanes through analysis of their histories, programmed structural modifications, and planned assignments. For reasons set forth in Section I (Introduction), we found that such long-range predictions of the structural life of individual aircraft tend to be meaningless and unnecessary. This realization led to the development of the following dual objectives and of recommended actions to attain them:

- Obtain improved long-range predictions of the safe remaining structural life of groups of aircraft (e.g., all Navy F-4Bs) to be used statistically to facilitate and support decisions regarding major structural modification programs, programmed aircraft model service life and service life extensions, and planning of the future military role to be filled by given aircraft models.

- Obtain improved short-range predictions of the structural condition of individual aircraft, which can be used to develop a maintenance strategy (e.g., inspection intervals) which would increase the probability of aircraft meeting operational commitments without major structural problems.

Those individuals interested in a management overview of findings and recommendations may limit their reading to Sections I, II E, and III.

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I. INTRODUCTION

A. Background and Initial Objective

Since early 1970 the Naval Aviation Integrated Logistics Support Center (NAILSC), in response to a request[1] from the Naval Air Systems Command (NAVAIRSYSCOM), has been developing analytical techniques for determining optimum aircraft service life and maintenance intervals. Under Task 72-12[2] The Logistics Management Institute (LMI) undertook to assist the NAILSC in the development of a model to predict aircraft structural integrity. Although the description of the model contained in the Task Order is not specific, NAILSC personnel had developed a more detailed concept of the nature of the model which was needed. They conceived of a model which would provide accurate analytical predictions of the safe remaining structural life of individual aircraft under any given operational and maintenance strategy.[3] The NAILSC concept was consistent with concepts of other cognizant Naval personnel with whom we discussed the problem and with other stated objectives within NAVAIRSYSCOM. In particular the Naval Air Development Center at Warminster, Pennsylvania, contained an organization which was tasked to

[1] Air Task A04-00004-6004-004D0000 43 of 27 February 1970.

[2] Appendix 1 is a copy of the Task Order.

[3] The model, interfacing with existing systems and programs, was to be served by a planned, but undefined, "Historical data base."

> . . . provide data on a periodic reporting basis concerning the structural fatigue life expended on each naval aircraft in the fleet except transport and rotary wing types. The purpose is to establish and maintain a system that will give a continuing indication of the fatigue life status of each operational aircraft in the Navy.[1]

Thus the concept of a model to predict the structural integrity of individual aircraft formed the basis for LMI's original objective.

B. Long-range Predictions

After considerable analysis we realized that long-range predictions of the safe remaining structural life of individual aircraft are inherently meaningless for the following reasons.

- Predictions of the remaining safe structural life of an aircraft or of a structural component of an aircraft present a paradox. In fact, the prediction of a catastrophic failure of a component (or part) will lead to modification and inspection programs which will tend to prevent that catastrophic failure from occurring.
- When structural damage or symptons of weakness are discovered during an inspection,[2] the discovery triggers actions which tend to prevent such damage from causing accidents on any individual aircraft of the model in question.

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[1]Technical Objective of Research and Technology Work Unit Summary 78012-74-84 of 1 November 1971.

[2]Including the extensive ones at the depot level.

- A catastrophic failure, particularly when the aircraft involved is recovered, also kindles actions which reduce the chances of the same type of failure occurring in the future.

Put another way, each component failure, or discovery of weakness, should result in action which decreases the probability of accidents caused by failure of that component in other aircraft. In fact, if all components of a type are used and abused at about the same rate, the more components there are of a type the greater is the expected life of any specific component. This is because, as the number of components of a type increases, any given component of the type is less likely to be the first of that type to fail. Therefore, it will stand a better chance of having its remaining life increased through lessons learned from other failures within the large population.

The problem is even more complicated when predictions of the structural life of components and parts are extended to apply to complete aircraft. Individual aircraft change with time. They are undergoing modifications resulting from analyses of findings regarding all aircraft of the type. The extent and types of inspections which individual aircraft receive are also changing as a result of such findings and analyses. This complication, coupled with a knowledge of the paradoxical, self-destructive nature of predictions of the structural failure of any component on an airplane, leads to the conclusion that long-range predictions of the safe remaining structural life of individual aircraft will be of limited validity and use.

Information is needed regarding the long-range structural integrity and safe remaining structural life of groups of aircraft (e.g., all Navy F-4Bs) to facilitate and support many important decisions. Fortunately, those decisions do not require a prediction of the long-range future status of each aircraft. Instead, statistical information regarding the group can be sufficient. Examples of questions requiring such decisions[1] are:

- Should a major structural modification procurement program be undertaken? If so, when?
- When should a replacement aircraft procurement program be undertaken?
- What military role can a given aircraft model be depended upon to fill during each of the forthcoming years?

C. Short-range Predictions

The realization that long-range predictions of safe remaining structural life are valid only for groups of aircraft meant that our original objective[2] had to be modified. Prerequisite to this modification was an analysis to determine the types of decisions which should be based on predictions of the structural condition of individual aircraft. Examples of questions requiring such short-range decisions are:

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[1] Structural considerations are only one important factor of several influencing such decisions. For example, a structurally sound aircraft model may be phased out because of other inadequacies.

[2] See section I A.

- Should a given aircraft be retired?
- Should a major structural modification be made to a given aircraft during its current depot level maintenance period, or is it safe to postpone the modification for at least one more tour?
- Should the operational performance envelope of a given airplane be limited?
- Should a given aircraft be grounded because of a discrepancy discovered during a preflight inspection?

Damage and casualties could occur should such decisions be based upon predictions which are optimistically in error. Thus it is fortunate that the paradox inhibiting long-term predictions of the safe remaining structural life of individual aircraft does not ?ect short-term predictions of whether a given aircraft is "safe" ?r its next flight or for its next service tour. In fact, the paradox does not become seriously significant until predictions regarding individual aircraft are made for times further in the future than the next depot level maintenance period. The reason for this is that during a given service tour the configuration of individual aircraft tends to be relatively stable since major modifications are normally made as aircraft undergo depot level mainentance.

This situation is implicitly recognized by the Naval Aviation Maintenance Program. The current philosophy followed by the Navy, insofar as depot level maintenance on structures is concerned, can be summarized as "to do the minimum amount of work which will assure that an aircraft will get safely through its next service tour."[1] When a Naval depot level maintenance activity completes periodic rework on an aircraft, it, in effect, is predicting that the aircraft will safely (from a structural standpoint) complete its next service tour, assuming:

- Effective organizational and intermediate level maintenance programs.
- No failures caused by operational overstresses.
- No failures of those structural elements not inspected during the periodic rework (because the probability of a consequential discrepancy was thought to be outweighed by inspection costs).

Likewise, any time during a service tour that an aircraft "passes" an inspection, someone is making a short-range prediction that the aircraft is safe for flight until the next comparable inspection--assuming that everyone else responsible for aspects of structural integrity has also made sound short-range predictions.

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[1]The following is quoted from the glossary of OPNAV Instruction 4790.2, which will be discussed at some length in Section II C 3 b.

> Standard Rework: Work performed on an aircraft at Naval Air Rework Facilities or other Rework Facilities after (and as a result of) completion of a prescribed period of operational service. The end-product specifications of the work will permit the aircraft to serve a full standard period of operational service before undergoing Rework again.

For a Depot Level Maintenance Activity (or any other activity) to make valid predictions of the probability of an aircraft safely completing its service tour, information is needed as to the planned organizational and intermediate level maintenance during the tour. If the predictions are to remain valid, information must be obtained regarding deviations from the planned programs, as well as any "surprises" detected during the course of intermediate and organizational maintenance. Data on other aircraft[1] may be important for revising predictions or, alternatively, as a basis for revising organizational and intermediate level maintenance programs.

D. Revised Objectives

We have shown that long-range predictions of the safe remaining life of individual aircraft are not meaningful unless used statistically. We have also discussed the important decisions for which statistical long-range predictions are needed.

In addition, we have discussed the types of important decisions which are based on short-range[2] predictions of the structural conditions of individual aircraft. In this regard, we have noted how the Naval Aviation Maintenance Program relies on such predictions to minimize accidents and have noted the interdependence of the predictions.

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[1]Reports of depot and field maintenance, accident reports, etc.

[2]There are no absolute criteria for differentiating between long and short-range predictions. However, almost all predictions of future structural status extending further into the future than the end of the next depot level maintenance period will be long-range.

In view of the above we restated our initial objectives as follows:

- Review current methods of making long-range predictions of the safe remaining structural life of Naval aircraft, recognizing that such predictions are valid only for groups of aircraft. Recommend changes, if appropriate.
- Recommend sound measures to obtain better short-range predictions, within the Naval Aviation Maintenance Program, of the structural condition of individual Naval aircraft. Insure that recommendations recognize the interdependence of all the short-range predictions. The result should provide the basis for developing a maintenance strategy which would minimize structurally related accidents for a given operational strategy, with given maintenance resources.
- Structure recommendations so that they will lead to an effective coordinated Naval Aircraft Structural Integrity Program. In developing recommendations build on existing and planned programs, systems, and organizational units to the maximum feasible extent.

E. Organization of Report

Section II of this report gives details of the analyses conducted in furtherance of the objectives stated above. Section II E is a summary of findings. Our review of current and planned Naval efforts led to the conclusion that early, cost-effective achievement of our objectives, through building on current systems and programs, is feasible. Further, results of the actions recommended should be beneficial to future systems and programs. Four major interrelated recommendations are presented in Section III. Each recommendation, if accepted, would require action by NAVAIRSYSCOM Headquarters. From a technical standpoint, the first recommendation represents the heart of the report, while the other three call for essential prerequisite actions.

Appendix 1 is a copy of Task Order 72-12. Appendix 2 is a discussion of aircraft structural integrity efforts within the U. S. Air Force.

II. SURVEY OF POLICIES AND PROGRAMS

A. Background

This section is an account of the analyses conducted in furtherance of the objectives set forth in Section I D. Readers not interested in details may skip to Section II E (page 42) where findings are summarized to form a basis for recommendations in Section III. Recommendations are deferred until Section III because the various interrelated factors leading to them made it impractical to follow an individual discussion with a recommendation.

B. Organizational Considerations

NAVAIRSYSCOM has prime responsibility for the acquisition, maintenance and disposition of aircraft within the Navy. The Commander NAVAIRSYSCOM reports to the Chief of Naval Material who, in turn, reports to the Chief of Naval Operations. Figure 1 shows the Headquarters organization of the NAVAIRSYSCOM. The offices most involved in the problem at hand are the NAVAIR Project Management Offices, the Material Acquisition Division (05), and the Logistics/Fleet Support Division (04).

The current approach to the acquisition of major systems is to assemble a relatively small project manager team to manage projects through the production phase. Project managers depend on functional organizations to perform project tasks and hence are competing for available talent within the functional divisions. As might be expected from organizational titles, assistance to project managers tends to be principally from the Material

Acquisition Division. For example, five persons from that organization are designated as Assistant Project Managers for the Model S-3A ASW Aircraft Weapon System Project while only one person from the Logistics/Fleet Support Division is so designated.[1]

The titles of these two divisions are descriptive of their functions. Terms such as "concept formulation", "engineering and operational systems development", "procurement", "production" and "material acquisition", which appear frequently in the charter for the Material Acquisition Division, are more applicable to earlier than to later phases of an aircraft's life. Terms such as "maintenance engineering" and "logistics support", which are more applicable to the later operational phase, are prevalent in the Logistics/Fleet Support Division's charter. Jointly the two divisions are responsible for practically all aspects of aircraft structural integrity.

There are numerous directives outlining responsibilities and procedures for the interrelated actions required to design, buy, build, operate, and maintain aircraft. But nowhere is there a formal delineation of responsibilities for the important <u>time-phased</u> structurally-related actions required over the life span of a class of aircraft.[2] We recognize, that over the years completely adequate <u>understandings</u> have evolved regarding most structurally-related intra and inter-divisional procedures and responsibilities. However, these "understandings" have not

[1] Naval Air Systems Command Instruction 5400.9A of 2 January 1970.

[2] We are referring to guidance similar to, but less detailed than, that of Volume I of Aeronautical Requirement Number AR-30A of 3 August 1971. That publication sets forth life cycle policies, procedures, and responsibilities for Integrated Logistics Support of Naval aeronautical systems.

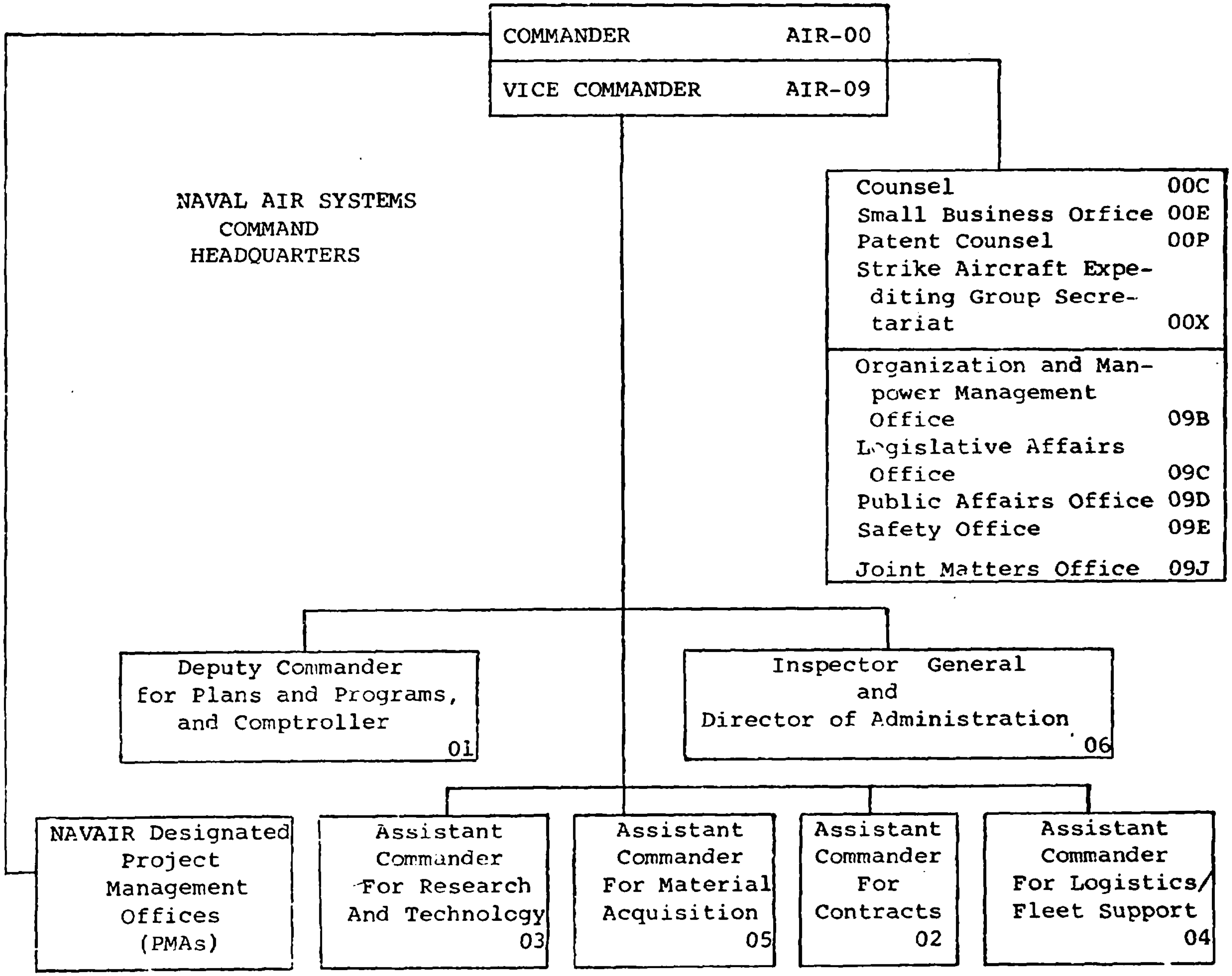
COMMANDER AIR-00
VICE COMMANDER AIR-09
NAVAL AIR SYSTEMS COMMAND HEADQUARTERS
Counsel 00C
Small Business Office 00E
Patent Counsel 00P
Strike Aircraft Expediting Group Secretariat 00X
Organization and Manpower Management Office 09B
Legislative Affairs Office 09C
Public Affairs Office 09D
Safety Office 09E
Joint Matters Office 09J
Deputy Commander for Plans and Programs, and Comptroller 01
Inspector General and Director of Administration 06
NAVAIR Designated Project Management Offices (PMAs)
Assistant Commander For Research And Technology 03
Assistant Commander For Material Acquisition 05
Assistant Commander For Contracts 02
Assistant Commander For Logistics/Fleet Support 04

Figure 1

been documented and reviewed in terms of the life cycle of an aircraft. Accordingly, there is danger of uncoordinated or inadequate actions. For instance, the current understandings might allow actions to be taken early in the life of an aircraft without due consideration of their long-term effect on structural integrity. In addition, the need for actions required at specific times during the life cycle may be overlooked until it is too late to achieve the most effective results. If these understandings were documented and related to the aircraft life cycle, areas of uncoordinated and inadequate coverage could be highlighted for appropriate action.

It is not realistic to expect an austerely staffed Navy Project Manager's Office to assume full responsibility for initiating, organizing, planning, and coordinating an independent integrated structural integrity program for its weapon system. A centrally coordinated effort is required. However, we are not able to advise the Navy of a single best way to resolve all procedural and interface problems related to structural integrity. Too many complex issues are involved, including jurisdictional and funding questions.

Although the Navy does not have a formal Aircraft Structural Integrity Program (ASIP), the Air Force has had one for more than 10 years. Details of the Air Force Program and comparisons of some pertinent Navy and Air Force aircraft structural integrity policies are given in Appendix 2. This information should be reviewed if it is decided that a better defined Navy ASIP is to be established. Recommendations regarding steps required for the clarification of responsibilities for aircraft structural integrity within the Navy are included in Section III D of this report.

C. Analysis

1. General

The Navy employs complementary "Safe Life" and "Damage Tolerance" structural integrity philosophies for its aircraft. The first of them, involving long-range predictions of safe remaining life from the Naval Aircraft Fatigue Life Program, is largely the responsibility of the Material Acquisition Division of the Naval Air Systems Command, while the second, which is more concerned with current an. short-range structural considerations, receives most attention from the Logistics/Fleet Support Division, through the Naval Aviation Maintenance Program (NAMP). In this section we discuss the two philosophies separately. Section III contains recommendations to obtain integration of the separate programs based on the two philosophies.

2. Safe Life Philosophy

a. Discussion

The safe life philosophy is not dependent upon the detection of fatigue cracks or other signs of impending failure to insure against catastrophic failure. Instead, through tests, an estimate is obtained of the average fatigue life of the various critical components of the aircraft model being considered. The fatigue life might be stated in terms of missions or related to cumulative damage associated with various measured and calculated loads.[1] Estimated average fatigue lives, in effect, are divided by a safety factor to obtain a life below

[1]An aircraft's condition relative to this life can be expressed in terms of life expended or safe life remaining.

which the probability of catastrophic failure of an individual aircraft is acceptably low.[1] When the most fatigue-critical component (or components) on an individual aircraft approaches its "safe life," a decision may be made to retire the aircraft or to replace one or more aging components. Alternatively, information from systems based on the safe life philosophy can be used to advantage for the timely planning of modifications to extend either the life of individual components or the overall aircraft service life. Data on individual aircraft can aid decisions regarding operational assignments. Statistical information from such systems can be useful in determining test specifications for future aircraft, while statistical information on remaining life can be used in support of budgets for new aircraft.

b. Naval Aircraft Structural Fatigue Life Program

The Naval Air Development Center (NADC) at Warminster, Pennsylvania, administers the Naval Aircraft Structural Fatigue Life Program.[2] In effect, this program[3] consists of a

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[1] In practice, usage or fatigue rates of individual aircraft may be multiplied by the safety factor.

[2] NADC's missions and functions are listed in enclosure 1 to NAVMAT (NAVAL MATERIAL) INSTRUCTION 5450.27 of 27 June 1972.

[3] Actually the program involves several related efforts guided and coordinated by NADC Aero Structures Department personnel. There is no single formal directive, or publication describing or defining such a program or its interfaces. This does not appear to have been of consequence in the past, but could be with an expanded system. Potential interface and problems of data duplication will be discussed later.

group of complex, iterative, evolving models or subsystems to predict expended fatigue life for selected classes of aircraft. In this section, we first present a simplified outline of a generalized fatigue life model. Then we discuss the current and planned scope of the Naval Aircraft Structural Fatigue Life Program. Finally, we discuss this Program's performance, related problems, and planned corrective actions.

(1) Generalized Aircraft Fatigue Life Model

In the course of designing an aircraft the static strength, fatigue life, and weak points of structural components are predicted analytically. To make the prediction, cumulative damage theory[1] is applied to information regarding probable mission profiles, technical information on included materials, and design data for the aircraft. In order for the predicted fatigue life at the various points of interest on the structure to be calculated, mission profile data must be translated into terms of loads at those points. Expensive and time consuming component and full-scale destructive tests under loads simulating those expected in actual operation are used to verify or modify the analytical predictions. The Navy employs a relatively severe load spectrum for the destructive testing and uses a safety factor of two when relating loads of operational aircraft to expected fatigue life. The tests also reveal, for corrective action as appropriate, problem areas not predicted by analytical techniques. Specially instrumented aircraft of the model being considered are used to obtain data to verify that actual loads at the various points of interest on the structure

[1] Twenty-one cumulative damage rules are referenced in Cumulative Damage in Fatigue with Particular Reference to the Effects of Residual Stresses, Royal Aircraft Establishment Technical Report 69237, November 1969. (AD 871 488)

are consistent with the analytical predictions. Data from similarly instrumented operational aircraft are used to validate or modify mission profile data.[1]

The preceding steps provide the basis for a fatigue life program. Usage data on operational aircraft can be weighted and translated into the percent of fatigue life expended for each individual aircraft. Different aircraft models and different points on a given aircraft are sensitive to different types of loads.[2] Structural modifications (e.g., installing new wings) may cause expected safe remaining life to increase.

(2) Current and Planned Scope

Expended fatigue life data and related information for more than 2000 individual Naval aircraft are currently included in the quarterly NADC Aircraft Structural Fatigue Life Program report.[3] Models RA-5C, A-6A, EA-6A, A-6B, A-6C, KA-6D, A-7A, F-4B, RF-4B, F-4J, RF-8J, F-8K, F-8L, and P-3A aircraft are covered at present. It is planned that eventually all

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[1] Special cameras are used to obtain information on sink rate so that statistical impact load information can be calculated.

[2] Flight (gust and maneuver) and ground (taxiing, towing, turning, take off, landing, and braking) loads. Catapulted take offs and arrested landings impose special requirements on carrier based aircraft.

[3] NADC personnel have indicated that when planned improvements and added capabilities are obtained, that this periodic report might be discontinued in favor of a quick-response on-request mode of operation. At the time this LMI report was written computer programs for the Naval Aircraft Structural Fatigue Life Program were being revised to provide a greatly expanded capability and responsiveness. The use of remote terminals by selected user activities was being considered.

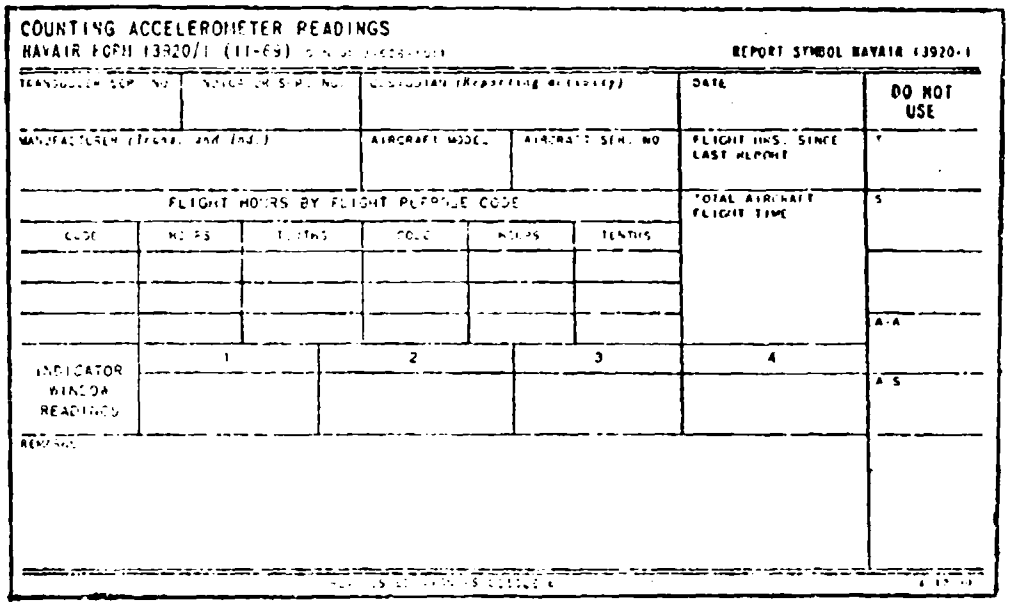
Naval and Marine aircraft except rotary wing and transport types will be tracked. In addition to data on individual aircraft in a tabular form, summary data by model are included.[1] Data in the report regarding expended fatigue life are limited to the one or two locations considered to be the most fatigue-critical on the aircraft. The locations invariably have been points on the wing.

The principal source of maneuver loads data for this program is counting accelerometers, which have been installed on more than 4000 Naval aircraft. A typical counting accelerometer consists of two units. One of the units is a transducer mounted near the center of gravity of the aircraft to sense accelerations caused by forces acting along the aircraft's vertical or normal axis. The second unit is an indicator which records the number of times that four specific positive accelerations are equalled or exceeded along the normal axis.[2] Using simplifying assumptions, each acceleration value is converted into values representing the minute fraction of life expended at points of interest. The fractions are added to the sum of previous calculations for the points of interest. If gust loads, landing loads, or ground-air-ground cycles are considered important for the fatigue-sensitive points being checked, they are factored in on a probability basis.

[1] In addition to percent expended fatigue life and percent expended fatigue life per 1000 hours a variety of additional data are listed for each aircraft. For example: aircraft acceptance date, aircraft custodian, total flight hours, flight hours in combat mode, arrested landings, catapulted take offs, etc.

[2] After a given G count is recorded the acceleration value must drop to a reset value before that given G value will be counted again.

Raw input data for individual aircraft are submitted by aircraft custodians or other designated agencies monthly or on a situation basis (e. g., upon transfer of aircraft). Figure 2 shows the specified form for the reports. Supplemental data regarding individual aircraft are obtained through the Navy Aircraft Accounting System.[1]


COUNTING ACCELEROMETER READINGS
REPORT SYMBOL NAVAIR 13920-1
DATE
DO NOT USE
AIRCRAFT MODEL
FLIGHT HRS. SINCE LAST REPORT
FLIGHT HOURS BY FLIGHT PURPOSE CODE
TOTAL AIRCRAFT FLIGHT TIME
TENTHS
1
2
3
4
INDICATOR WINDOW READINGS

FORM FOR COUNTING ACCELEROMETER READINGS

Figure 2

(3) Performance

There is no objective way of evaluating the performance of the expanding, relatively young, Naval Aircraft Structural Fatigue Life Program, which has no built-in tests for effectiveness. The Program does not predict either the probability of structural failure or indications of impending failure

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[1] Described in OPNAV Instruction 5442.2C.

as a function of calculated expended life. If it did, tests of effectiveness would be difficult to devise because of interacting effects of the maintenance program, which are not considered.

As noted earlier, current reports include calculated expended fatigue life for only one or two fatigue critical points on the wing. To the extent the system prevents wing failures at those points, its performance is practically perfect. If major accidents caused by all structural elements are considered, the picture is obscured. Before elaborating, we should say that we consider it to be an important, well-managed program, which should be an essential constituent of any evolving Naval Aircraft Structural Integrity Program.

Figure 3 shows the results of our analysis of Naval Safety Center records of accidents to Model A-4 series, RA-5C, A-6A, A-7 series, F-4B, and F-4J aircraft from January 1968 through December 1971. The data pertain to all major accidents[1] which, with the exception of control surfaces, were caused by the failure of airframe[2] components. This analysis is not rigorous

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[1]Major accidents are those that result in "ALFA" or "CHARLIE" damage. ALFA or strike damage of an aircraft involves damage which renders it of no further value, except for possible salvage of parts. CHARLIE or substantial damage involves destruction of a major component (e.g., vertical stabilizer) or damage such that the total direct hours required to effect complete repair to the aircraft equals or exceeds specified substantial damage limits. Currently the limits are 900 direct man-hours for all aircraft models listed in Figure 3, except for the A-4 series whose substantial damage lower limit is 400 direct man-hours. OPNAV Instruction 3750.6H.

[2]Airframe - The structural components of an airplane, including the framework and skin of such parts as the fuselage, empennage, wings, landing gear (minus tires), and engine mounts. Dictionary of United States Military Terms for Joint Usage JCS Pub 1.

in the sense that mathematical tests for significance can be applied to it. It is merely intended to place the problem in a broad perspective. For example, no effort was made to obtain correlations between accidents and such important parameters as flying hours and landings. From this Figure, the relatively broad spectrum of structural elements causing major accidents is evident. The comparatively few major accidents attributed to wing failures are particularly noteworthy. In this regard, wings were not indicated in accident reports as being a possible cause of any of the accidents resulting from the failure of "unknown" components.[1] Approximate annual rates of major accidents attributed to structural failures are also shown in Figure 3.[2]

Figure 3 indicates that from 1968 through 1971, only one of eleven structurally caused F-4B accidents, resulting in a destroyed aircraft, and only three of eight such accidents, resulting in substantial damage, were considered to be primarily caused by the failure of some wing structural element. During the same period only one of the eight

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[1]An accident report may indicate an accident to be caused by the failure of an unknown component. Under such circumstances, up to four components may be listed in the accident report as "possible cause factors."

[2]For each model being considered, the numbers of operational aircraft at the end of fiscal years 1968, 1969, 1970, and 1971 were obtained from the Office of the Chief of Naval Operations. Those values were summed and the result divided into the total number of ALFA and CHARLIE accidents attributed to structural elements during the 1968-1971 period for each aircraft model. The result was then multiplied by 100.

Model A-6A accidents was the direct result of a wing failure. Also, none of the thirty-three major accidents sustained by Models RA-5C, A-7 series, and F-4J aircraft was attributed to wing structural elements. The same is true of the twenty-four Model A-4 series aircraft accidents.[1] NADC personnel provided us with time-of-accident expended fatigue life estimates for the four F-4B and one A-6A aircraft mentioned above. This and related information are shown in Table 1.

Table 2 shows information similar to that in Table 1 for the other structurally caused accidents from Figure 3 for which expended fatigue life calculations for the most fatigue critical point on the wing were readily available. The expended life calculations shown tend to be higher than they actually were at the time of accidents, because values available to us from the NADC quarterly report were for considerably later times (up to about 3 years).

Tables 1 and 2 should not be interpreted as proof that there is no correlation between aircraft age, as determined by fatigue life calculations, and major accidents. The quarterly NADC Aircraft Fatigue Life Program report indicates that at a given time, those aircraft older than the median age for the model in question appear to be more likely to be involved in major accidents. Figure 3, supplemented by Tables 1 and 2, does conclusively illustrate the importance of tracking numerous critical structural components.

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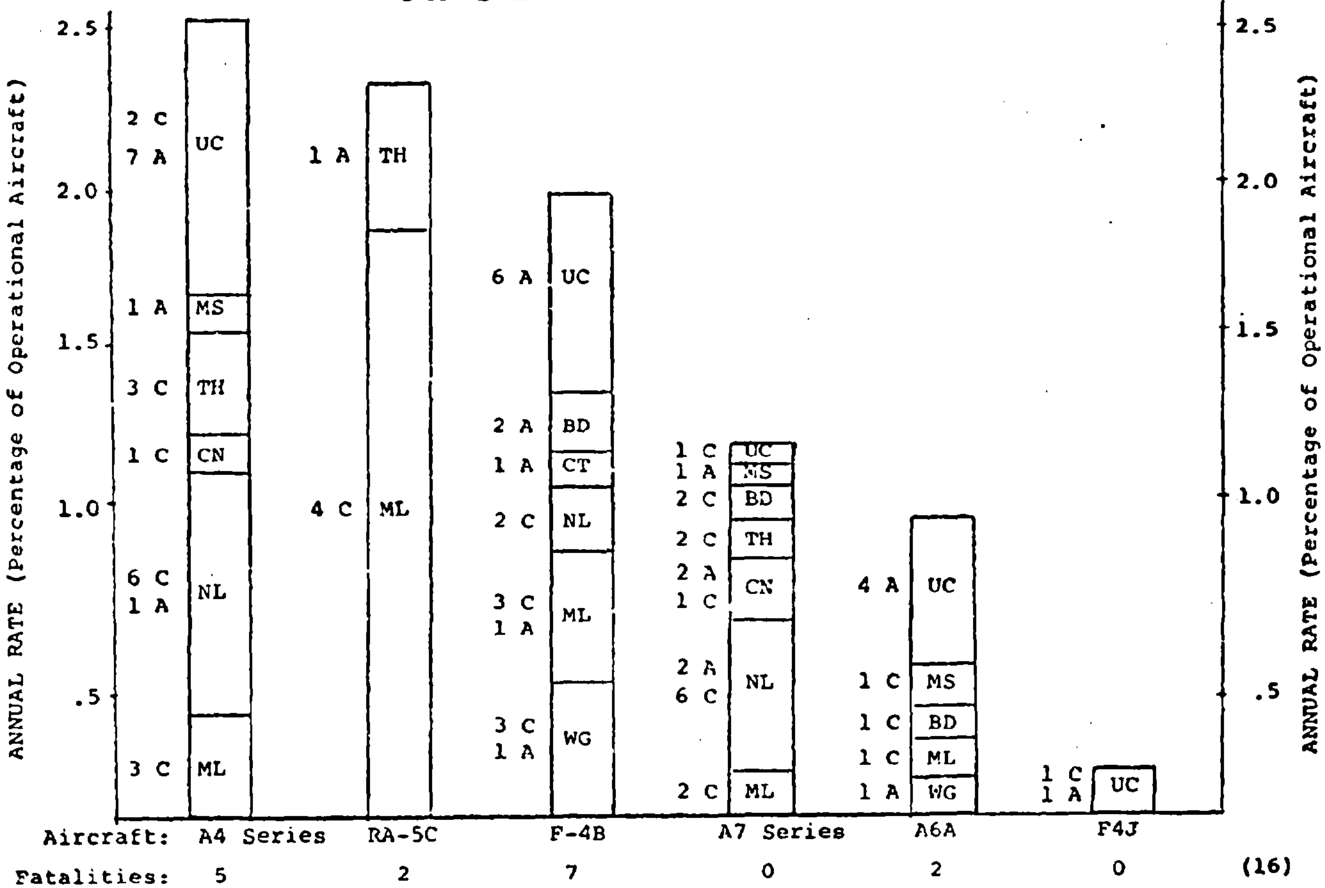
[1]The Model A-4 aircraft is not yet included in the NADC quarterly report which shows fatigue life expended.

MAJOR ACCIDENTS DUE TO STRUCTURAL ELEMENTS
DURING PERIOD 1968 THROUGH 1971
FOR SELECTED AIRCRAFT MODELS



LEGEND: A - ALFA Damage/Destroyed Aircraft (32)[1] C - CHARLIE Damage/Substantially Damaged Aircraft (45)[1]

BD - Bleed Air Duct
CN - Canopy
CT - Catapult Tow Hook
ML - Main Landing Gear
MS - Miscellaneous
NL - Nose Landing Gear
TH - Tail Hook
UC - Unknown Component
WG - Wing

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[1]See footnote 1 on page 20 for definitions of accident categories.

Figure 3

Table 1

Background Information on Five Aircraft Accidents Caused by Wing Structural Failures

Aircraft Model	Aircraft Number	Accident Date	Aircraft Acceptance Date	Accident Category[1]	Approximate Fatigue Life Expended[2]	Primary Cause per Accident Report	Remarks
F-4B	148392	12-16-69	8/61	CHARLIE	35%	Port Outer Wing Panel Broke	Attributed to manufacturing defect
A-6A	156998	6-12-70	1/70	ALFA	6%	Starboard Wing Separated During Bombing Practice	Accident report indicated that a progressive crack in wing was initiated by tensile overload
F-4B	152250	8-10-70	4/65	CHARLIE	45%	Starboard Outer Wing Section Separated	Attributed to fatigue and fretting
F-4B	153048	9-30-70	8/66	ALFA	19%	Failure of Starboard Wing During Combat Maneuver	No evidence of fatigue on portion of wing recovered. Aircraft involved in wheels up landing on 6/67. Cockpit accelerometer recorded 8.2 Gs a few flights previous to mishap.
F-4B	151445	3-18-71	2/64	CHARLIE	45%	Wing Structural Failure	First Symptom was explosion in wing torque box

[1] See Footnote 1 on page 20 for definitions of accident categories.

[2] Calculated Fatigue Life expended at critical point on wing.

TABLE 2

STRUCTURALLY RELATED ACCIDENTS RESULTING IN SUBSTANTIAL DAMAGE, VERSUS CALCULATED EXPENDED LIFE AT MOST FATIGUE CRITICAL POINT

Aircraft Model	Bureau Number	Date	Cause	Expended Life %
A6A	152912	1-68	LD	25
A6A	154167	10-68	ML	28
A6A	151819	2-71	BD	59
A7A	153266	9-68	NL	14
A7A	154353	10-68	NL	13
A7A	154354	4-69	ML	8
A7A	153158	1-70	NL	5
A7A	154351	2-70	ML	8
A7A	154351	5-70	BD	8
A7A	153170	8-70	CN	11
A7A	153226	10-70	NL	14
RA5C	150839	2-68	ML	36
RA5C	147858	1-69	ML	38
RA5C	147856	2-70	ML	18
RA5C	149298	5-70	ML	62
F4B	151400	11-68	NL	16
F4B	153030	3-69	NL	37
F4B	151415	3-70	ML	17
F4B	152980	5-71	ML	24
F4J	153811	10-70	UC	56

BD - Bleed Air Duct LD - Landing Gear Bay Door NL - Nose Landing Gear

CN - Canopy ML - Main Landing Gear UC - Unknown Component

Section III B of this report includes a recommendation that the NAVAIRSYSCOM's policy regarding the tracking of fatigue critical interchangeable components be reviewed and strengthened.

(4) Problems

In this section we discuss known problems and shortcomings of the Naval Aircraft Structural Fatigue Life Program. Some result from constraints on funds and personnel and some are related to the state of the art. All are known to NADC management. Within the limits of their resources, they have progressive programs which, in the long term, could resolve all except one important shortcoming. Recommendations to correct that problem are made in Section III A. Nine problem areas are listed below:

- Accelerometers are not a safety of flight item and when rework funds have been in short supply, as they now are, needed repairs and calibrations have not always been performed. Available correspondence, substantiated by conversations with cognizant depot maintenance personnel, indicates that a high percentage (near 70%) of the accelerometers on aircraft inducted for depot level maintenance need repair or calibration or both.

- Current counting accelerometers do not measure negative accelerations or give information as to the sequence of loads, both of which can be important.

- Accelerometer recorders and transducers of different manufacturers have been installed on the same aircraft, giving erroneous data.[1]
- It is not unusual for squadron personnel to make mistakes in recording accelerometer readings for submission to NADC.
- Statistical rather than actual landing and take-off loads are used.
- Statistical assumptions regarding altitude, speed, and stores are used in converting accelerometer readings to estimated loads for the various points of interest on an airplane.
- Loads on only a few components can be calculated with meaningful accuracy from accelerometer readings. The relationship between accelerometer readings and loads on important structural elements such as control surfaces, vertical fins, and landing gear either are not known or not well known. (The contributions of components other than the wing to major-accident rates were shown in Figure 3 in the previous section.)
- It is difficult to relate the fatigue life of the few test articles to components of operational aircraft. It is expensive and time consuming to test components and full scale structures to destruction. For example,

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[1]When there are gaps or suspected errors in accelerometer data for an individual airplane, "conservative" methods are used to calculate expended fatigue life. That is, it is assumed that usage of the aircraft for the period in question was relatively severe.

only one wing is fatigue tested for a new aircraft model. Nominally identical items may have significantly different fatigue lives even when tested under the same load spectrum in the laboratory. When different load spectrums are used, corresponding to what happens with operational aircraft, variances tend to be greater.

- A major shortcoming of the current Aircraft Structural Fatigue Life Program is that it does not use real life data regarding the actual condition of individual components and aircraft to update or correct its predictions. Operational aircraft face important environmental conditions not typical of the laboratory-like atmosphere under which components and structures are tested. Corrosion, often hidden, may greatly reduce the time to failure of operational aircraft.[1] The degrading effect

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[1] The following abstract is from a 14 May 1971 Naval Air Rework Facility, Jacksonville letter reporting on an in-depth analysis of two Model RA-5C aircraft and the wing inboard panels from two other RA-5Cs.

"1. The in-depth structural ARP produced several major results. The most significant being that the current method of estimating the percent of service life expended, on individual RA-5C aircraft, does and will present misleading data unless the adverse effects of stress corrosion are taken into effect.

2. The number and critical location of cracks noted on BUNO 150834's wing inboard rear spars is revealing in view of the aircraft's minimal percentage fatigue service life expended (22%). Similar anomalies are evident on several aircraft. Review of the aircraft fatigue life data shows that aircraft having less than 29% service life expended, range in calendar age from 1.5 years to 7 years. It is apparent that if a realistic percent service life expended figure is to be assigned to individual aircraft, then the older aircraft must be adjusted to compensate for exposure to a corrosion environment."

on structural life of environmental factors interacting with fatigue is implicitly considered in the safety factor of two applied to all aircraft. This will be high for some aircraft and low for others. Fortunately most of those for which it is too low will be detected by inspections. For those for which it is high, components and aircraft with much safe remaining life may be uneconomically discarded.

(5) Planned Corrective Actions

As noted above, the NADC management has programs[1] which in the short or long-term should eliminate all major shortcomings except the last one mentioned. The programs include:

- Relatively inexpensive, more reliable counting accelerometers are being delivered. Emphasis is being placed on insuring that they are repaired and calibrated.
- Quality assurance checks are used to segregate suspect data for special attention and corrective action. Improvements are incorporated on a continuing basis.
- Programs to develop improved instruments are being pursued. Included in this category are accelerometers which would measure negative accelerations and improved strain gages (possibly calibrated to indicate expended fatigue life) which would measure actual structural deformations at points of interest. Related developments

[1]See footnote 3 on page 17, regarding planned expanded capability.

by industry and the other Services are monitored to minimize duplication and to take full advantage of advances in the state of the art.

- A continuing emphasis on the use of specially instrumented aircraft to obtain better information on operational load spectrums, including negative accelerations and load sequences.
- Studies and test programs, underway and planned, whose goal is to establish the relationship between the fatigue lives of similar components under different load spectrums.

(6) A Neglected Major Shortcoming

No significant effort is currently planned by NADC personnel to permit data regarding environmental effects on operational aircraft to be considered by their fatigue life model. They realize it is an important factor, but are doubtful whether responsibility for solution of the problem should fall within the purview of a fatigue life program. Conversely, Logistics/Fleet Support Division personnel, who are largely responsible for correcting manifestations of environmental problems in the maintenance of operational aircraft, do not feel responsible for initiating action to improve a Material Acquisition Division sponsored program. Complicating the problem, there is very little historical data now available which could be analyzed to determine the significant indicators of impending failure or of remaining structural life of components and aircraft, which have undergone interacting loads and environmental stresses. This situation should be borne in mind during the following discussion of the "Damage Tolerance Philosophy."

3. Damage Tolerance Philosophy

a. Discussion

The Damage Tolerance Philosophy for preventing catastrophic accidents is based on programs to detect signs of impending failure in time to repair or replace defective components. These are essentially efforts to schedule inspections as to depth and frequency so that a flaw or crack will not get out of hand between inspections. Inspections involve various forms of nondestructive testing, ranging from visual checks to tests using complex, ultra-sophisticated equipment. Nondestructive testing is a field in which rapid advances are being made.

Frequency of inspection may be measured in such terms as calendar time, flight hours, number of flights, catapulted take-offs, landings, arrested landings, hard landings, or inflight overstresses. Aircraft tour lengths determine the inspection intervals for structural elements that are not normally checked except when undergoing depot level maintenance. Inspections at unduly short intervals are not economic from a maintenance standpoint. At the other extreme, when inspection intervals are too long, aircraft and personnel are endangered. Information potentially valuable for optimizing inspection intervals and for guiding corrective efforts (e.g., modifications to strengthen weak or worn areas) is developed each time there is an inspection, particularly if a discrepancy is discovered.

To be most effectively used, reports of inspections and of other discrepancies (e.g., accident reports) need to be systematically analyzed, individually and statistically, together with other pertinent information to determine cause-effect relationships.

b. The Naval Aviation Maintenance Program

(1) Background

It will be assumed that the reader is familiar with the Department of Defense three-level maintenance[1] concept upon which the Naval Aviation Maintenance Program (NAMP) is based. Policies, procedures, and responsibilities for the conduct of the NAMP are set forth in OPNAV Instruction 4790.2. There is no indication in that comprehensive instruction that any organizational unit, subprogram, or subsystem has the responsibility for the systematic collection and analysis of data for the purpose of making quantified predictions of the structural integrity of Naval Aircraft.[2] Consequently, other than to note that we were generally favorably impressed, no attempt will be made to appraise the performance of any of the NAMP elements. Instead they will be reviewed as potential sources of the data required for attainment of the objectives of this LMI task. Serious shortcomings are the subject of recommendations in Section III.

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[1] Organizational, Intermediate and Depot. DoD Directive Number 4151.16.

[2] The Naval Air Systems Command, after considering all pertinent data available in various forms, annually makes recommendations, by aircraft model, to the Chief of Naval Operations regarding tour length, aircraft service life, allowable catapulted launches, and other similar information. Approved life limits or goals are shown by aircraft model, qualified in some instances, in the current version of OPNAV INST. 3110.11. One of the objectives of this LMI task is to recommend actions which would facilitate the preparation of the Naval Air Systems Command's inputs to that OPNAV Instruction.

(2) Promising Data Sources

(a) Depot Level Maintenance

The potentially valuable engineering information revealed by the thorough inspections at Naval Air Rework Facilities (NARFs) cannot be readily collated or used for systematic analyses[1] because reports of discrepancies are hand written.[2] Existing NARF data systems tend to be "supply and production control" oriented. Relatively sophisticated data systems report such things as expended man-hours in great detail, but give little or no information as to the specific nature of discrepancies or of their seriousness.

In the past, consideration has been given to implementing Navy Maintenance and Material Management (3M) System data reporting requirements at NARFs, pending the availability of planned longer term NARF engineering data systems.

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[1]The Analytical Rework Program (ARP) comprehensive reports are an exception. However, this important program is primarily an engineering evaluation type of work to determine effectiveness and need for changes in other rework programs. To a large extent it is looking for symptoms of impending problems in areas of aircraft not normally examined under standard rework programs. It is necessarily a limited program. If its findings and those of other rework programs shared a common data base, engineering analysis capabilities within the NARFs would be greatly enhanced.

[2]Section 2.24 of enclosure 1 to NAILSC letter F-4 ILS04-03-71 of 23 Sep 1971 relates problems of attempting to convert handwritten discrepancy reports into a form suitable for systematic analysis.

However, except for possible limited application to the repairable (F/J) components program, no implementation within NARFs is currently planned.[1] Simple implementation of 3M reporting requirements by NARFs would not materially improve their engineering analysis capability, because of limitations imposed by the current "malfunction code" structure (this is discussed in Section II C 3 b (2) (b), which follows).

In our opinion, the lack of effective engineering data systems at NARFs is the most serious single obstacle inhibiting the establishment of a meaningful coordinated Naval Aircraft Structural Integrity Program.

(b) Operational and Intermediate Maintenance

Discrepancies discovered during the conduct of intermediate or operational maintenance, as well as corrective actions, are reported via the 3M System.[2] These data are theoretically amenable to analysis to determine their probable implications on structural integrity. In practice, a lack of preciseness in the current 3M coding structure would limit the extent that they could be used to supplement data from an effective NARF engineering data system. This shortcoming, from the standpoint of effectively coordinating structural integrity

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[1] This policy reported in Commander, Naval Air Systems Command letter AIR-41412B:DMR of 2 Jan 1970 was verified by conversations with AIR-41412 personnel in August 1972.

[2] Including those related to Conditional Inspections. Conditional Inspections are unscheduled inspections required as the result of a specific situation or set of conditions, e.g., hard landing inspections. Glossary of OPNAV Instruction 4790.2.

efforts, applies both to "malfunction codes"[1] and "Work Unit Codes."[2] NAILSC has several reports addressing these problems.

The resolution of these problems is not obvious. It is not as simple as restructuring code structures to report discrepancies in precise engineering terminology. The net result of such a step might well be that hardworking maintenance personnel would spend additional unproductive time preparing erroneous reports. A workable balance between such an extreme and the current situation would provide valuable information with minimum additional reporting requirements.

(c) <u>Safety Unsatisfactory Material/ Condition Reports</u>

Safety URs (Unsatisfactory Material/ Condition Reports) are prepared and processed under various

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[1]The following is an essentially exhaustive list of the meanings of malfunction codes which might be used to report structural discrepancies: Worn, chafed, or frayed; Broken; Missing parts; Loose or damaged bolts, nuts screws, rivets, fasteners, clamps or other common hardware; Missing bolts, nuts, screws, rivets, fasteners, clamps or other common hardware; Cut; Deteriorated; Adjustment or alignment improper; Binding, stuck or jammed; Chattering; Corroded; Cracked; Leaking-internal or external; Nicked; Pitted; Punctured; Sheared; Loose; Bent, buckled, collapsed, dented, distorted or twisted; Delaminated; Chipped; and Torn.

[2]A major problem in the Work Unit Code (WUC) area is that WUC-11000, which refers to the entire airframe, is frequently used rather than one which applies to the specific area of the discrepancy.

serious or potentially serious situations.[1] Engineering investigations frequently result from Safety URs. A standard format, which is being revised, is employed for URs. At the time this report was written, it was planned that completion of action on a Safety UR would be signified by a report, also in a standard format. Safety URs involving aircraft, and related requests for engineering assistance are sent directly to specified NARFs for action.[2] Safety URs are potentially important sources of information for a structural integrity program. (The Naval Safety Center, Norfolk has coded all Safety URs since 1968 and stored the information on magnetic tape.)

(d) Aircraft Logbooks

Aircraft logbooks include records of rework, major repairs and flight operations, damage, maintenance

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[1] In accordance with page 8-2, Vol. III OPNAV INSTRUCTION 4790.2 safety URs are submitted when:

(1) An aircraft accident/incident or ground accident occurs wherein material failure/malfunction, quality control, technical documentation, or maintenance procedures are considered to be contributing cause factors.

(2) An explosive/accident/incident/malfunction is involved.

(3) The existence of a known condition which, if not corrected, will or could result in death or injury to pilot, crew, maintenance personnel, or other persons or loss of aircraft.

(4) An urgent change is required to safety or loading or handling instructions to prevent a hazardous condition from occurring.

(5) Urgent action or assistance is required or requested.

(6) Corrective action must be completed at an early date because of operational safety or logistic requirements.

[2] Commander Naval Air Systems Command letter AIR-411:EFL of June 26, 1972.

directives, and the more important inspections. From our standpoint, the greatest potential usefulness of aircraft logbooks appears to be as a source of information on a case basis (e.g., after an accident).

D. Additional Factors and Sources

1. Nondestructive Testing and Inspection

Nondestructive Testing and Inspection (NDTI) is defined as "those methods that may be applied to a structure or component to determine its integrity; composition; physical, electrical, or thermal properties; or dimensions without causing a change in any of these characteristics."[1] Rapid advances have been and are being made in NDTI techniques and equipment capabilities. And personnel at Headquarters and in the field are effectively and energetically pursuing individual programs.[2] However, it is our judgment that NDTI is not receiving the coordinated, high level emphasis and guidance it merits. Section III C includes recommendations regarding this.

2. Configuration Status Accounting

a. Background

For our purposes, Configuration Status Accounting (CSA) can be considered as keeping track of the structural

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[1] This definition is from the glossary of OPNAV Instruction 4790.2. A synonymous term Nondestructive Inspection (NDI) is favored by the U. S. Air Force. The term Nondestructive Testing (NDT), also having the same meaning, occurs frequently in the literature on aircraft structures.

[2] NAVAIR Instruction 13070.1 of 22 July 1969 established a focal point for Nondestructive Testing and Inspection Information.

configuration of individual aircraft relative to a baseline structural configuration. Information is needed both as to when structural modifications are made during an aircraft's life and which modifications are pending.

The NAVAIRSYSCOM's CSA System is described in Technical Manual 00-25-602. This system is operated by the two Naval Air System Command Representatives (NAVAIRSYSCOMREPs) (Atlantic and Pacific), who are in the chain of command between the Commander, NAVAIRSYSCOM and the NARFs. If either of the two Pacific Coast NARFs is the Cognizant Field Activity (CFA) for a specific aircraft model, then the NAVAIRSYSCOMREP Pacific is responsible for configuration status accounting for all individual aircraft of that model. The NAVAIRSYSCOMREP Atlantic has that responsibility for aircraft models for which one of the five east coast NARFs is the CFA.

Conceptually, the NAVAIRSYSCOM's CSA System is composed of four subsystems. The one of primary interest to us is the Standard CSA Subsystem. Along with other information, data on applicable Technical Directives,[1] upon which action has been completed and upon which action is pending, are available for each individual Naval aircraft. Information is updated

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[1] "TECHNICAL DIRECTIVE - An approved NAVAIR document prepared to disseminate information and/or instructions to Fleet or Naval Shore establishments which directs a material change, repositioning, modification, or alteration in characteristics of equipment or directs an initial inspection to determine whether a given condition exists." Glossary of Naval Air Systems Command Technical Manual, NAVAIR 00-25-602.

cyclically, through the 3M System.[1] Individual aircraft components are not identified by serial number in the Standard CSA Subsystem. This could present a serious problem for anyone using this subsystem to track fatigue critical components, particularly those that are routinely interchanged between aircraft. Disregarding cost, other subsystems of the CSA System could be used to track individual components. However, no specific recommendations are made herein that this be done because of factors discussed in Section II D 2 c below.

b. <u>CSA for the Naval Aircraft Fatigue Life Program</u>

NADC personnel have not made much use of the NAVAIRSYSCOM CSA System as a source of input data for the Naval Aircraft Fatigue Life Program. They are only interested in the few fatigue-critical points that they are tracking on aircraft and depend largely on arrangements with NARF personnel and contractors' representatives for status information on modifications of interest. They also depend on such arrangements for information regarding the replacement of the major components of interest, principally wings. The current NAVAIRSYSCOM CSA System probably would serve NADC as a source of modification data as well or better than their current sources. On the other hand, NADC's current method of obtaining information on components whose past history is important is probably superior and, so long as relatively few components are involved, satisfactory. In the long-term, if more fatigue-critical points per aircraft are tracked, the current method will present greater danger of inefficiency, undesirable duplication of effort, and of failure to obtain important needed information.

[1] Insofar as we know, this is the one instance of NARFs reporting via the 3M System.

c. Weapon Systems File

There are plans to replace the current NAVAIRSYSCOM CSA System by a modified version, which would be a part of the Weapon Systems File operated by the Aviation Supply Office, Philadalphia. A target date of May 1973 for initial loading of data elements may not be realized because of funding problems. Access to the system from remote terminals is planned. The data structure will provide for a "top down breakdown" of individual aircraft into its installed systems, subsystems, equipments or components, sub-components and parts. Initially, it is planned that the only serial numbers entered in the file will be for overall aircraft. However, if selected components are to be tracked, the Weapon Systems File might provide the best way of doing it. In any event, there is danger of undesirable duplication unless the potential capability of the Weapon Systems File is studied in connection with any review of data requirements for the Naval Aircraft Structural Fatigue Life Program and any related emerging structural integrity programs. Unless there is continuing liaison during planning stages, unnecessary interface problems may result. Section III B includes more specific recommendations regarding the Weapon Systems File.

3. Aircraft Accident Reports

The Naval Safety Center at Norfolk Virginia encodes information from each Navy Aircraft Accident Report (AAR) and stores it on magnetic tape. Data fields include: accident[1] date,

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[1]"Navy Aircraft Accident. A Navy aircraft accident is an occurrence involving one or more Navy aircraft operating with intent for flight and results in strike, substantial, or minor damage to any one of the Navy aircraft. . . . Death or injury to personnel and/or damage to property where the aircraft is not also damaged does not constitute a Navy aircraft accident. A missing aircraft will be considered to have been involved in a major aircraft accident and will be reported as such." Page I-1 of OPNAV INSTRUCTION 3750.6H (Navy Aircraft Accident, Incident, and Ground Accident Reporting Procedures)

aircraft model, aircraft serial number, extent of damage, primary cause (which may be unknown), contributing causes (if any), service tour, flight hours since acceptance, last inspection type, flight hours since last inspection, days since last inspection, flight hours and months since last depot level maintenance, and the NARF which conducted the last depot maintenance for the involved aircraft. There are also provisions for listing up to three involved components, one component involved after-the-fact, one component contributing to the accident because of a design deficiency, and a narrative. In addition, fields are also available for several categories of specific information on up to three involved components (e.g., manufacturer's part number and total flight hours). The AAR files are of great potential value to any Naval Structural Integrity Program.

4. Aircraft Accounting System

Under the Naval Aircraft Accounting System, Operating Units (generally) report on a one-time basis each incident of aircraft status or custody change, each instance of flight (including such things as purpose of flight, number and type of landings, and catapulted take-offs), and each instance an aircraft is Not Operationally Ready (NOR) or in a Reduced Material Condition (RMC).[1] The 3M system is used to collect data.[2]

NADC personnel reported that special reports from operating units (see Figure 2 on page19) have suited the requirements of the Naval Aircraft Structural Fatigue Life Program better

[1]OPNAV Instruction 5442.2C provides policies and guidance for the Naval Aircraft Accounting System.

[2]Chapter 6, Volume III of OPNAV Instruction 4790.2 discusses use of the 3M System for this purpose and includes illustrative reports from the Aircraft Accounting System.

than data from the Aircraft Accounting System. We have no specific information regarding current error rates, but consider that data from the Naval Aircraft Accounting System will be useful for longer term Naval aircraft structural integrity efforts.

5. Miscellaneous

The Army, industry, civilian airlines, and particularly the U. S. Air Force, are potential sources of important useful information for planning and implementing a Structural Integrity Program.[1]

E. Summing Up

- Major accidents to Naval Aircraft are caused by structural failures of a variety of components.
- Long-range predictions of the safe remaining structural life of individual aircraft will be of limited validity unless used statistically. This is because predictions of structural failure are self-destructive in that they kindle actions which reduce the probability of the predicted event occurring on any aircraft. Accidents and discoveries of discrepancies during inspections also trigger events which tend to extend structural lives. Fortunately, most important decisions based on long-range predictions of the safe remaining structural life of aircraft do not require a prediction of the status of each aircraft. Instead statistical information regarding groups of aircraft (e.g., all F-4Bs) are needed to

[1] See Appendix 2.

facilitate and support decisions regarding such things as structural modification programs, planned aircraft service life and service life extensions, and the replacement of current aircraft with new models.

- Sound short-range predictions regarding the structural condition of individual aircraft are needed to minimize damage and casualties from structural failures. Information regarding the past history of important interchangeable structural components is a needed input for a system making such predictions. The system making short-range predictions of the structural condition of individual aircraft should be a part of, or work very closely with, a system to develop optimum maintenance strategies, including tour lengths.

- The Naval Aircraft Structural Fatigue Life Program (for long-range predictions of safe remaining structural life) and the Naval Aviation Maintenance Program (for short-range predictions of the structural condition of individual aircraft) are sound, complementary bases for a coordinated Structural Integrity Program.

- The Naval Aircraft Structural Fatigue Life Program has one serious shortcoming, for which no corrective actions are currently planned. This shortcoming is an inability to use information on environmental effects as a basis for modifying expended life calculations.

- Establishment of a meaningful coordinated Aircraft Structural Integrity Program requires the systematic collection and analysis of historical maintenance and failure data. Much of the needed data are now available in various locations and formats. The most significant problem areas involve absence of engineering data systems at Naval Air Rework Facilities (NARFs) and coding limitations of the 3M System.

- The rapid rate of progress in the Nondestructive Testing and Inspection (NDTI) area will continue. Therefore, greater emphasis will be placed on the use of NDTI as a tool for evaluating the condition of aircraft structures. Benefits of planned improvements (Section II C 2) to the Naval Aircraft Structural Fatigue Life Program will be severely limited unless NDTI results are used to supplement fatigue life calculations.

- The important field of NDTI has not received the coordinated high level emphasis and guidance it merits.

- There are no directives formally setting forth overall life cycle procedures and responsibilities for functional organizational units concerned with Naval Aircraft Structures. As a result of such things as custom, charters, job descriptions, and directives of limited scope, most related problems are efficiently and effectively resolved. Nevertheless documentation of time phased responsibilities is needed if an integrated or coordinated Naval Aircraft Structural Integrity Program is to be established.

III. RECOMMENDATIONS

All four of the following interrelated major recommendations, if accepted, would require action and coordination by NAVAIRSYSCOM.

A. Establish a coordinated Pilot Program to achieve dual interrelated objectives. The first of these is the improvement of long-range predictions of the safe remaining structural life of Naval aircraft by modifying expended fatigue life calculations through the use of information on environmental effects. The second objective is the development of a capability to make short-range predictions of the structural condition of individual aircraft to provide the basis for establishment of a self-correcting maintenance strategy which will minimize structurally related accidents for a given operational strategy and given maintenance resources.

1. Discussion

The Pilot Program would involve two complementary interfacing subsystems. One of these, the Long-range Subsystem, based on the current Naval Aircraft Fatigue Life Program, would exploit information obtained from NDTI to obtain improved long-range predictions of safe remaining life. Eventually, we believe that long-range predictions by NADC should and will give more emphasis to NDTI findings as the NDTI program (and the associated state of the art) is expanded. In addition, more fatigue critical points should be tracked as available instrumentation and NDTI equipment capabilities improve. By and large the data would be used statistically[1] to aid long-range planning, including budgetary justification for major structural modifications (either to achieve planned service life or to extend it) and for new aircraft. We envision a subsystem which would have the capability to show the probable effect, projected to any given future date, of various possible alternative programs (e.g., flying hour program, projected mission mix, modification program) on the safe remaining life (i.e., number of aircraft, mean safe remaining life and variance) of the aircraft model in question. Current computational procedures followed by the Naval Aircraft Fatigue Life Program could be continued for the one aircraft model involved in the Pilot Program until there was confidence that incorporation of feedback data regarding the actual condition of aircraft was resulting in better predictions.[2]

The complementary Short-range Subsystem would provide information which could be used to minimize structurally caused accidents for given maintenance expenditures and operational strategies. This subsystem would not require the establishment of a new Navy-wide system, but rather the systematic collection, collation, and analysis of available data. Basically, it would involve a determination of a baseline condition

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[1]An important exception might be the use of data on individual aircraft to plan aircraft assignments to avoid imbalances in projected expended life calculations.

[2]At the time this report was written computer routines were being revised to achieve additional capabilities and enhanced responsiveness.

for all structurally critical components on the aircraft at the completion of depot level maintenance. This baseline, determined in the course of quality assurance inspections, would be supplemented by statistical information on other aircraft and from other programs.[1] Maintenance and operational data received during the service tour would be used to update the baseline, which would be thoroughly checked the next time the aircraft was inducted for depot level maintenance. Information regarding significant deviations from the expected--either for the aircraft in question, other individual aircraft, or groups of aircraft--would be used to enhance the accuracy and degree of quantification of both long and short-range predictions.[2]

Predictions from the two subsystems should be compatible and tend to converge as aircraft or components approach retirement age. Both subsystems could provide information useful for the design of new aircraft. Information from the first subsystem should be useful in planning changes in programmed service life. Information from the second subsystem should be equally useful for determining optimum tour lengths, inspection intervals, and extent of rework.

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[1] Such information would be particularly valuable if the ACE (Aircraft Condition Evaluation) concept, being investigated by NARF North Island is implemented. Under the ACE concept, service tours of individual aircraft might be extended up to 18 months, depending upon the results of an intensive evaluation in the field by NARF personnel at the same time as the last calendar inspection prior to scheduled induction for depot level maintenance.

[2] For example, a structurally related accident, upward trends in maintenance actions, or the discovery during analytical rework of serious corrosion in an inaccessible area.

Disregarding "structural integrity programs" as such, the implementing actions recommended herein are warranted by the benefits which will accrue to the NARF Engineering Cognizance Program and to longer term NARF Engineering Data Systems, whose development is being coordinated by the Management Systems Development Office (MSDO) Naval Air Station, North Island. Information from the proposed effort could be used benefically for practically all decisions and planning for maintenance and modifications. Systematic analysis of indications of fatigue in corrosion free areas of a wing, where NADC can calculate loads with high confidence from accelerometer readings, should be useful for evaluating and improving expended fatigue life predictions.

2. <u>Required Implementing and Important Related Actions</u>

- Designate one NARF to work with NADC personnel in developing the Pilot Program. Select an aircraft model for the program, for which that NARF is the prime rework activity.

We have worked with most of the seven NARFs, in the course of this and other tasks, and believe that any of them has the capabilities needed for the Pilot Program. However, NARF Jacksonville appears to be particularly well suited for this undertaking. Their personnel have shown great interest and proficiency in the establishment of rework cause-and-effect relationships. They have also done preliminary work on a computer based Maintenance and Technical Data Management Information System for the Model A-7 aircraft.[1] Their

[1] This work was in response to Air Task A-235/105 2354 0001 of Jan. 7, 1972. Two unfunded phases of this air task would have involved development of a capability to track selected A-7 components and use of an expanded data base to support engineering analyses related to A-7 aircraft.

conceptual system would have provided rework data on the A-7 required for a meaningful Structural Integrity Program. Like the other NARFs, they have displayed an active progressive interest in NDTI. The relatively young Model A-7 aircraft, for which NARF Jacksonville is the prime rework activity, is a suitable aircraft choice for the recommended program.

- Implement a small computer-based engineering data system at the NARF selected for the project.

Resources required for such a system would be minute compared to the long-term payoff potential. Very little developmental and programming effort would be involved, since the system would be based on the Aircraft Corrosion Reporting System developed by and in operation at NARF Norfolk.[1] There would have to be some modification and expansion of the "type" and "category" codes to satisfy the requirements of engineering personnel analyzing reports of inspections and corrective actions. For example, codes indicating fatigue in the absence of corrosion and codes indicating various forms and degrees of physical damage would be necessary. Likewise, type codes indicating various combinations of fatigue, corrosion, and physical damage would be needed. The aircraft model to be tracked and the fatigue-critical and corrosion-prone points on that model would determine the resultant "area" code structure.

In addition to a variety of technical decisions (e.g., which components and fatigue-critical areas would be tracked) which would be resolved by NADC and NARF personnel, decisions

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[1] The System is described in Naval Air Rework Facility Norfolk Instruction 13070.1B.

will be required regarding such things as interfaces, data format, compatibility and location, and configuration status accounting.[1]

Safety of Flight Unsatisfactory Reports and reports of related investigations should be stored in the system unless, in connection with the assumption by NARFs of primary cognizance for action on URs, it is decided that there are more advantageous ways of handling them. In any event, URs will be an important source of information.

- Insure close and continuing liaison and interchange of information between the Pilot Program and NAILSC/MSDO.

This is particularly important because of implications of this project on planned data systems. In addition, NAILSC has either completed or is working on several related tasks. The following are particularly pertinent: AIR TASK A 04-00004-6004-004D0000 43 of 27 February 1970 (Optimum Maintenance Cycle Determination Technique),[2] AIR TASK A4024141-2014-14020000-12 of 30 November 1970 (NAVAIREWORKFAC (Naval Air Rework Facility) Engineering Data System), and AIR TASK A402 4211 2014 1402 000007 of 27 July 1971 (Frequency Approach to Scheduled Maintenance Program).

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[1]Section I of the LMI Report jointly covering Tasks 69-14 (rev.) and 70-17 (Implementation Plan for the Naval Air Industrial Management Information System) AD 726 195, set forth procedures which could be effectively applied for the purpose of resolving interface problems.

[2]The Air Task which precipitated this LMI Task.

- Insure close and continuing liaison between the Pilot Program and the Analytical Rework Program.[1]

In particular, the fatigue/environmental effects reporting system should be applied to ARP reports.

- Liaison should be established between the Pilot Program and the Naval Safety Center to insure maximum benefits from their reports.

In addition, consideration should be given to the advisability of using their historical file of Safety URs.

- Liaison should be established between the Pilot Program and the Air Force Logistics Command organization responsible for the development of the U.S. Air Force Centralized Aircraft Structural Integrity Management Information Center (See Appendix 2).

- Check the long-range predictions of "remaining life" by NADC and the short-range predictions of "structural integrity" by the NARF involved in the Pilot Program by destructive tests of components from operational aircraft.

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[1]The purposes of the short-range subsystem are so interrelated with the objectives of the ARP, set forth in NAVAIRINST 4700.8 of 19 November 1969, that consideration should be given to sponsorship by the ARP of the designated NARF's efforts. A proposed revision to NAVAIRINST 4700.8, being considered as this report was written, would not materially affect this close relationship.

Crash-damaged aircraft are another potential source for components for destructive tests, provided there is confidence that the crash did not affect the component.[1] A testing program of this nature would necessarily be limited in scope because of expense. However, the alternative is greater reliance on accident data to evaluate predictions which would involve loss of life and even greater expense. Extensive nondestructive tests should accompany the destructive tests. This would serve the dual purpose of improving predictions based on NDTI and provide a means of discounting, at least in part, the artificial laboratory atmosphere under which destructive tests are conducted.

- Review available flight loads data (load factor spectra) for the designated aircraft model. Measures to correct any inadequacies should be taken.

- Review for optimality, NDTI equipment allowances for the NARF involved in the project and those of organizational and maintenance activities for the designated aircraft model.

- Advise Operational and Intermediate Maintenance Activities for the designated aircraft model of the project and keep them appraised of its progress.

[1]The Boeing Aircraft Company recently purchased, for structural analysis and mock up use, a bomb damaged Boeing 707-320C aircraft, whose airframe had undergone 40,000 operational hours. Page 71, Aviation Week and Space Technology, September 25, 1972.

- Give special emphasis to obtaining improved 3M data for the designated aircraft model.

Continuing emphasis of the importance of the project to involved Operational and Intermediate Maintenance Activities, coupled with quality control checks of data, should keep error rates low. However, unless Work Unit Codes and Failure Mode Codes are made consistent with those of the NARF Engineering Data System discussed above, much potentially valuable data will be lost (See page 49).

B. <u>The NAVAIRSYSCOM's policy regarding serializing and tracking fatigue critical interchangeable parts and components should be reviewed, strengthened, and related to overall longer term structural integrity efforts</u>.

When an aircraft is inducted for depot maintenance it is given a thorough inspection. Selected repairable components are removed and sent to shops for further inspection and repair. Reassembly of airplanes begins within a few days after induction. Component turn around times in shops frequently exceed the period that components can be off aircraft under an orderly reassembly schedule. In such instances components may be drawn from a pool of spares. The units previously removed from aircraft replenish the pool once repairs are completed. Thus, an airplane shown by the Aircraft Structural Fatigue Life Program to have a small amount of its fatigue life expended can leave the depot with a critical component which had been previously installed on an airplane with much fatigue inducing usage.

The problem extends to parts of components. Parts of disassembled components are often interchanged in shops.

It is likely that the mixing of aged and young components contributes to the wide variance shown in Table 2. The failed components have obviously used 100% of their life, even though many of the fatigue calculations for what was considered to be the most fatigue critical point on aircraft indicate relatively little facigue life expended.

Under current policies only a relatively few critical components are tracked from aircraft to aircraft. These components are accompanied throughout their life by either a Scheduled Removal Component (SRC) card or an Aeronautical Equipment Service Record (AESR).[1]

Serious shortcomings and problems associated with current policies are broadly recognized throughout the Naval aviation community.[2] Ultimately, practically all critical interchangeable parts and components should be tracked by serial number, perhaps with the assistance of optical readers. Use of the Weapon Systems File for centralized storage of such data should be considered.[3]

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[1]Volume II, Chapter 6 of OPNAV INST 4790.2 includes current guidance on SRC cards and AESRs.

[2]It is known that positive actions for improvement are underway. Naval Air Systems Command Code 411 recently assumed additional responsibilities in this area and Commander, NAVAIRSYSCOM Letter AIR 41111/963:AVC of 12 July 1972, requested comments on a proposed instruction which would to a large extent satisfy the recommendation.

[3]See Section II D 2 c on page 40.

C. <u>Headquarters management of NDTI Programs under the cognizance of the NAVAIRSYSCOM should be reviewed and strengthened</u>.

(Section II D 1 on page 37 gives background regarding this recommendation, while preceding portions of Section III include numerous references to the importance of NDTI.)

D. <u>Responsibilities and related procedures should be documented to assure that aircraft structural integrity matters receive timely and commensurate attention</u>.

Finally, we recommend a review of the subject of Naval aircraft structural integrity from a <u>life cycle</u> viewpoint. This review should result in a directive showing responsibilities for required <u>time-phased</u> actions. The necessity for different treatments for new and operational aircraft models should be addressed. Specific attention should be given to insuring that structural integrity life cycle considerations are given due emphasis in important planning and programming documents, not primarily concerned with structural integrity.

APPENDIX 1

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ASSISTANT SECRETARY OF DEFENSE
Washington, D. C.

Installations and Logistics DATE: 22 October 1971

TASK ORDER SD-271-168
(Task 72-12)

1. Pursuant to Articles I and III of the Department of Defense Contract No. SD-271 with the Logistics Management Institute, the Institute is requested to undertake the following task:

A. TITLE: Optimum Service Life Determination Technique

B. SCOPE OF WORK: The NAILSC (Naval Aviation Integrated Logistic Support Center) has instituted a program to develop a technique for determining, for various aircraft models, maximum economical service life, and optimum tour lengths and inspection cycles. One of several portions of this effort is a subsystem to predict aircraft structural integrity. Under this task LMI will assist the NAILSC by designing a subsystem to predict aircraft structural integrity, thus generating measures which will feed into the total system for determining optimum service life. Included will be a model to accomplish the aircraft structural integrity subsystem portion.

2. SCHEDULE: A final report will be submitted to the NAILSC on or before 30 September 1972.

APPROVED /s/Glenn V. Gibson
10/22/71

ACCEPTED /s/ Wm. F. Finan

DATE 26 October 1971

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APPENDIX 2

AIRCRAFT STRUCTURAL INTEGRITY POLICIES OF THE U.S. AIR FORCE[1]

I. Background

Although the Navy does not have a formal Aircraft Structural Integrity Program (ASIP), the Air Force has had one since 1958. General requirements and responsibilities for the ASIP are set forth in Air Force Regulation 80-13 of 31 July 1969. Responsibilities of Headquarters, U.S. Air Force, the Air Force Systems Command (AFSC), the Air Force Logistics Command, (AFLC) and other commands are spelled out in considerable detail in that instruction. Detailed ASIP technical requirements and responsibilities for new aircraft are contained in Technical Report ASD-TR-66-57[2] of the Aeronautical Systems Division (ASD) of the Air Force Systems Command.

The ASIP is indicated in Air Force Regulation 80-13 as consisting of the following six interrelated phases:

Phase I. Design criteria and planned operational usage.

Phase II. Design Analysis (Loads, stress, fatigue, flutter, and sonic analysis; and design development and pre-production verification tests).

Phase III. Testing (Structural component tests, full scale static, fatigue, flutter and sonic tests, flight loads survey and dynamic response).

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[1]This appendix is largely based on a Report on the Study of Structural Integrity of Current and Future Air Force Systems dated 1 July 1971. That comprehensive report was in response to a memorandum request dated January 9, 1970 from the Secretary of the Air Force to the Chief of Staff USAF.

[2]At the time this report was being written proposed MIL-STD-XXXX (USAF) "Aircraft Structural Integrity Program Airplane Requirements" was being routed within the Air Force for review and comments. When issued it will supersede ASD-TR-66-57.

Phase IV. Service Life Analysis (Strength summary and operating restrictions, service life prediction; parametric fatigue analysis).

Phase V. Operational Usage (Life history recording program; actual operational usage reports. These data feed back into Phase IV studies and analyses to update and revise).

Phase VI. Inspections (Special instructions as required, analytical condition inspections (ACI), and inspect and repair as necessary (IRAN)[1] inspections).

AF Regulation 80-13 also requires that a Structural Integrity Master Plan be prepared for each specific aircraft weapon system (e.g. F-15) during the "contract definition and acquisition phases." This plan is indicated as being "for the entire life span of the aircraft from contract definition phase through operational phase out. Included in the Master Plan will be the aircraft service life requirements, as well as a detailed ASIP data flow diagram which assigns specific data collection, reduction, dissemination, storage and analysis responsibilities. The Plan will be included as part of the procurement documentation for the contract definition phase and subsequent contracts."

The extent to which the provisions of AF Regulation 80-13 and ASD-TR-66-57 are to be applied depends on the age of aircraft. Complete ASIP requirements are specified for all future aircraft developed by the Air Force and for aircraft currently in concept definition or acquisition phases.

[1]Corresponding to Progressive Aircraft Rework (PAR) within the Navy.

II. Status

Since AF Regulation 80-13 and the Master Plan approach are relatively new, the only Master Plans prepared during the "definition" phase have been for the B-1 and F-15. To keep RDT&E costs down, the competitive prototype A-X contract did not impose exhaustive ASIP documentation requirements. However, it is expected that full compliance with AF Regulation 80-13 will be required for the production contract.

An extensive ASIP was established for the B-58 before it was phased out. Under that program, cumulative fatigue damage was calculated for more than a dozen fatigue critical points.

Other aircraft models known to have active coordinated structural integrity programs include the F/RF-4, F-111, B-52, C-5, C-130, C/KC-135, C-141, A-37B, and T-37.

III. Aircraft Structural Integrity Management Information System (ASIMIS)

The Air Force is developing a large centralized management information system to support the ASIPs for their individual aircraft models. The Oklahoma City Air Material Area (OCAMA) has been designated as the development activity and centralized computer facilities for the system will be located at the OCAMA.

ASIMIS will include a consolidated data base for each selected aircraft fleet which will include expended fatigue life calculations, maintenance data, accident data, aircraft usage history, configuration status accounting data, and information on critical interchangeable components. ASIMIS will interface with the Air Force Advanced Logistics System (ALS).

The ASIMIS development plan places great emphasis on fatigue life calculations. For example, the terms fatigue life and service life are indicated to be synonymous, within the context of that plan.

IV. Nondestructive Inspection (NDI)[1] Program

NDI efforts within the Air Force are much more formally organized and centrally directed than those of the Navy. Air Force Regulation 66-38 of 5 February 1971 states policies and objectives and assigns responsibilities for implementing and maintaining the NDI program. The Air Force Logistics Command (AFLC) has been designated as the lead command on NDI matters. Program control is exercised through a NDI manager at the San Antonio, Air Material Area (SAAMA).

Standard tables of allowances have been prepared for organizational, intermediate, and depot level maintenance activities.[2] Much attention has been given to the preparation of the -36 series Technical Manuals, which set forth prescribed NDI procedures for the various aircraft models (e.g. Technical Manual T.O. IF-4C-36 gives NDI procedures for F-4C, F-4D, F-4E, and RF-4C aircraft).

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[1] Nondestructive Inspection (NDI), used within the Air Force, and Nondestructive Test and Inspection, used within the Navy, are synonymous terms.

[2] Within the Navy standard allowances are provided for organizational and intermediate level maintenance activities, but not for depots.

Technical Manual T.O. 33B-1-1,[1] which is a comprehensive discussion of NDI methods, is also the responsibility of the NDI Program Manager SAAMA. This manual was being completely revised at the time this LMI report was being written.

V. Organization for Acquisition

Whereas the Navy assembles a relatively small project manager team to manage projects through the production phase, policy within the Air Force is to assemble an essentially self sufficient organization for the purpose. Thus it is not feasible for the project manager within the Navy, who is largely dependent upon functional organizations, to be held responsible for all aspects of structural integrity. However, it is at least theoretically more feasible to assign such a responsibility to Air Force System Program Directors, as is done. Both methods of organizing Project Offices for major acquisitions provide a satisfactory basis for establishment of an effective ASIP.[2] Our recommendation III D is intended to improve coordination between Navy functional organizations on structural integrity matters.

VI. Miscellaneous

The Air Force tends to use two full scale articles for fatigue tests, while the Navy normally only uses one. The Air

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[1]Available within the Navy as NAVAIR 01-1A-16

[2]LMI Report 72-6 (The Program Manager Authority and Responsibility) AD 748622, discusses program management policies of the Navy, Air Force, and Army in some detail. That LMI report includes detailed analyses of the program management of two programs of each Service: Air Force - A-X and F-15, Navy - F-14 and S-3A, and Army - Safeguard and Scout Vehicle.

Force normally uses "realistic" test spectra and a safety factor of four. The Navy favors relatively "harsh" test spectra and uses a safety factor of 2.

The Navy's goal is to install counting accelerometers on all of its fixed wing aircraft, except transports. Aircraft, specially instrumented with relatively sophisticated recorders, accelerometers, strain gauges, and other sensors are used on a case basis to obtain required supplemental data. The Air Force tends to supplement its counting accelerometer data by installing VGH (Velocity, G-accelerations, height) recorders on a sizeable fraction of its operational aircraft.